Multiparameter data acquisition system for spectroscopy

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A powerful and versatile, simple to use multiparameter data acquisition system has been implemented for use in spectroscopy. In its standard configuration, the system can acquire signal from 16 time-to-digital converter channels, 16 analog-to-digital converter channels, and 12 scaler inputs. The system was put to use on the electron beam ion trap experiment to record the output from four position-sensitive proportional counters in two soft x-ray spectrometers together with the signal from an x-ray pulse height analyzer. Also recorded are the electron beam energy and the pulse height distribution of the proportional counters. All data are recorded as a function of time. Because the relevant parameters are recorded simultaneously, software gates instead of hardware gates are used to select the data of interest. This has led to a substantial cost saving over earlier data acquisition systems. Data are stored in binary or in ascii format for system-independent processing. The operation of the system is demonstrated in a measurement of the *M*-shell soft x-ray spectrum of gold. We used the system to record the 3–4 and 3–5 transitions of gold (Au^{44+}–Au^{51+}) excited with a simulated Maxwellian with electron temperature of 2.5 keV. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1310584]

I. INTRODUCTION

For the past 10 yr, the electron beam ion trap (EBIT) spectroscopy effort relied on a disk operating system (DOS) based data acquisition system that allowed digitization with up to two 10-bit and two 13-bit analog to digital converters (ADCs). This system afforded limited time resolution in the form of a data router and a 32 kByte memory module. Subsequently, a second, four-channel system provided event-mode data acquisition for tagging spectroscopic data with the energy of the EBIT electron beam. This arrangement proved limiting in instances where spectroscopic data needed to be tagged with more than one parameter, for example with time (in radiative lifetime measurements), beam energy (for sorting excitation processes), and detector pulse height distribution (for sorting noise from first or second order x-ray signals). Moreover, data stored on optical disk drives routinely became unreadable through changes in the data tree formats when minor updates of the operating system (DOS, WINDOWS, and drivers for optical storage) were implemented. Many hours were spent recovering data, and in the end over 2 GByte of data were irretrievable. A new data acquisition system was needed that matched the data producing capabilities afforded by the Livermore EBITs.

In the fall of 1998, the decision was made to develop an advanced event-mode data acquisition system optimized for spectroscopy. Building on an event-mode system employed at the University of Nevada Reno for coincidence measurements of collision fragments,[1] the new system was developed

quickly and was ready to acquire data within 3 months.[2] In January 1999 the new system replaced our old acquisition systems, becoming the standard acquisition system for EBIT spectroscopy. The new system is based on KMAX software from Sparrow Corporation running on the Macintosh platform. Its ease of use and expansion has significantly reduced setup time, allowed new classes of measurements, and greatly increased scientific return.

The multiparameter system allows us to acquire each photon event tagged with such parameters as the time, the photon energy, the spectral position, and the energy of the electron beam. Our present system handles about 40 simultaneous input parameters. Our experience with data handling and storage has been excellent, and data integrity has no longer been an issue. Data storage (typically on CDs; DVDs in the future) in both binary and ASCII formats is available for system-independent analysis at a later time, which is important because of the great number of users from different universities and laboratories at our facility. We are helped by the ease of setting up AppleTalk networking capabilities built into every Macintosh computer. This allows us to link different machines for data acquisition, data analysis, CD writers, etc., via fast ethernet without the need for internet protocol (IP) addresses. The data acquisition computer thus is protected from net vandals and hackers, as it is accessible only by other Macintosh computers within the local AppleTalk network. At the same time data from the acquisition computer can be transferred at high speed to other Macintosh computers that are in addition on a separate internet (TCP/IP) network and thus provide a means to transfer data to other computers around the world.

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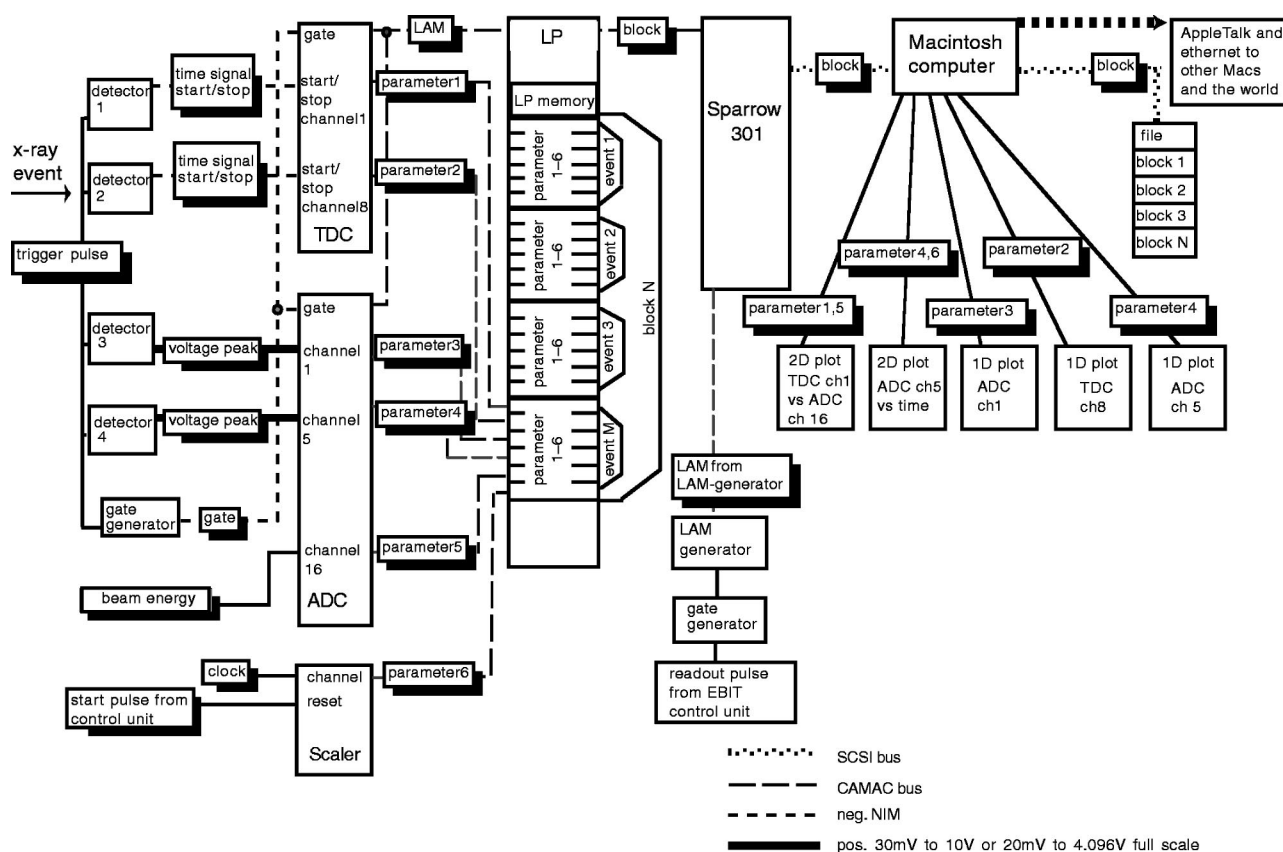[b)Permanent address: Technische Fachhochschule Berlin, Germany.

FIG. 1. Data flow in the event mode system.

II. THE EVENT MODE SYSTEM

Data digitization utilizes computes automated measurement and control (CAMAC) modules. For digitization, our core system employs a Phillips 7164 ADC and a Phillips 7187 time-to-digital converter (TDC), which can each digitize 16 signals with a 12-bit dynamic range, giving 32 total available channels. In addition, the system uses a Le Croy 2551 scaler that provides 12 24-bit channels for counting. In an extended mode, we have implemented a Hytec 520 ADC, which can digitize up to four signals, as well as two Le Croy 3512 single-channel ADC with Le Croy 3588 histogramming memories, and two Le Croy 2301 digitizers. For simplicity, we only describe the core system.

The CAMAC crate is controlled by a Sparrow 301 crate controller. It connects the crate via a small computer system interface (SCSI) bus to a Macintosh G3 computer. A Hytec LP 1341 list processor acts as an auxiliary crate controller, serves the digitizers in the crate, and is used as a hardware buffer. We have implemented the 256 kByte memory version, although versions with MByte buffer memory are available. Finally, a look-at-me (LAM) generator is used to generate a LAM signal that starts a readout of the list processor to the computer via the Sparrow controller.

A flow chart of the event mode data acquisition system is shown in Fig. 1. An event (for example, an x ray from EBIT) occurs and is detected by one of the detectors. The signal generated by the event in the form of either a start and stop (generally for position sensitive detectors) or a voltage peak (for example, from an energy-dispersive detector) is fed

into a TDC or an ADC channel, respectively. The detector that records an event also creates a trigger, which is used to generate a characteristic set of gates for all ADC and TDC modules. Because there is only a single gate for each digitizer all channels on each digitizer are converted even though only one has a true signal, the signal that created the gate. The ADC and TDC modules digitize after a gate or trigger and set a LAM signal when they are done. The list processor continuously checks the Phillips ADC for a LAM signal. If the LAM is present, the list processor waits for the TDC and the scaler to finish digitization. After that the list processor reads all the parameters. Then it loops again at the Phillips ADC and waits for the next event. The list processor program is illustrated in Fig. 2. To stop the list processor the instrument sets the instruction pointer of the list processor to a stop command, which is not shown in Fig. 2.

Each channel in each digitizer is assigned a parameter identification (ID) in the KMAX software. Because every active channel is digitized whether or not it triggered acquisition, every event has the same number of parameters. This makes it convenient to use the parameter number for distinguishing signals (data words) from different detectors. For example, in Fig. 1 parameter number six will always be the scaler and parameter number four will always be channel five of the Phillips ADC.

Once all units finished their digitization, the list processor writes all parameters into its data memory which is read out by the computer when the main controller recognizes a LAM from the LAM generator. After the block is in the
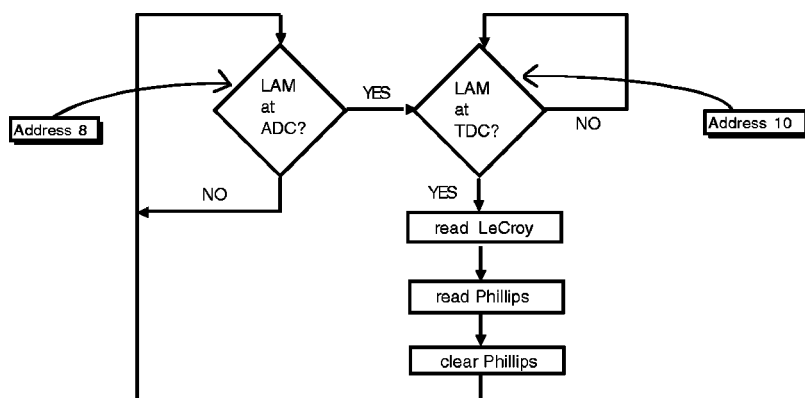
FIG. 2. List processor flow chart.

computer the parameters are sorted into histograms according to how the user wants to view them. For example, the data can be sorted on line to display x-ray spectra as a function of beam energy. Gates can be set to select only data from a certain time interval and data that fall into a selected range of the pulse height distribution of the proportional counter. The latter gates are used to sort, for example, first and second order reflections in a crystal spectrometer and to eliminate electronic noise.

Unless two or more events occur simultaneously at more than one detector, the system deadtime after an event is about 15 μs. No new events will be recognized during that time. It takes the Phillips and Hytec modules 10 μs to digitize a signal plus some CAMAC cycles for clearing LAMs and data registers in all digitizers.

The number of parameters determines the event size, while the count rate per second and the readout interval determine the block length. A block contains all events of one readout cycle. The block length cannot exceed the memory size of the list processor. Our 256 kByte list processor can store about 260 000 data words. This means, for example, it can store 26 000 events when ten simultaneous parameters are acquired for each event. Once the list processor is full all incoming events are ignored. There are two ways to deal with this situation. Either the list processor is read out automatically when it is full, or it is read out in a preselected time interval. We choose the latter and read out the list processor upon each EBIT cycle, i.e., while ions are dumped from the trap and the trap is refilled. Block data transfer from the list processor to the Macintosh computer takes less than 100 ms for a 100 kByte block. The list processor is immediately restarted after a data block transfer.

The control, acquisition, and simple analysis software is based on Sparrow Corporation's KMAX software. The "on-line" instrument allows the user to save the streaming raw data to an event data file for permanent archiving and subsequent analysis. The software also allows real-time viewing of the data in customized one-dimensional (1D) or two-dimensional (2D) histograms of up to 4096×4096 pixel per histogram. The selection of appropriate software gates filters out only those data the user wants to see. In many cases these plots represent the final data, and there is no need to analyze the raw data stream off line. The 1D or 2D histograms can be immediately written to binary or text files, as desired.

Short term data storage is provided by a 9 GByte hard

drive on the Apple G3 computer. A second copy of the data is transferred via an AppleTalk ethernet connection to the hard drive of a second Macintosh computer that is backed up on a daily basis to magnetic tape. Permanent data storage is provided by writing the data to compact disk. This medium yields excellent data integrity for long-term storage. Most importantly, the disks are burnt employing industry standards that can be read across most computer platforms. By contrast, data from our older acquisition system were stored on magnetic tape. These tapes cannot be read on any other device than the exact tape writer/reader that originally produced the tape, as tape formats were not standardized. In addition, we stored data on optical disks. Again, these can only be read with the exact optical drives that created the disks. Even worse, the drives and disks work only if the computer runs the exact software driver and WINDOWS operating system used when the disks were made. Entire disks became unreadable when we made small changes to either in the course of system maintenance.

The KMAX software is used to construct a software package for off-line sorting of the data. Off-line sorting may be required in instances when many complicated sorts are required that cannot be processed in real time while data are
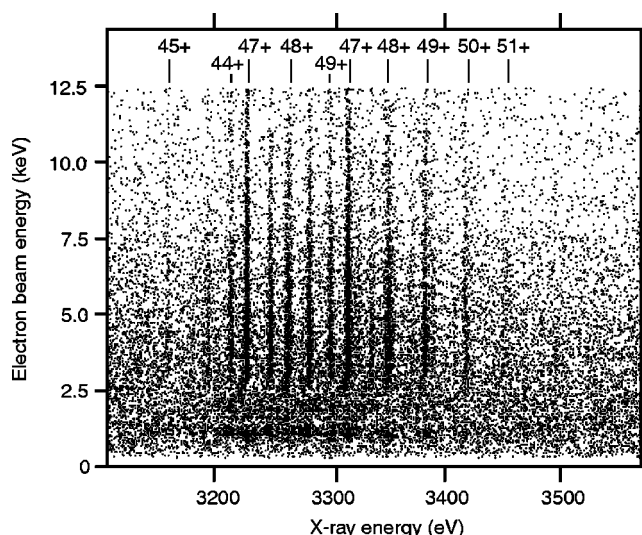

FIG. 3. Spectral emission recorded with a crystal spectrometer on EBIT as a function of the electron beam energy. Emission features are labeled by the charge state of the emitting ion. Dielectronic resonances are seen at energies below threshold for direct excitation.
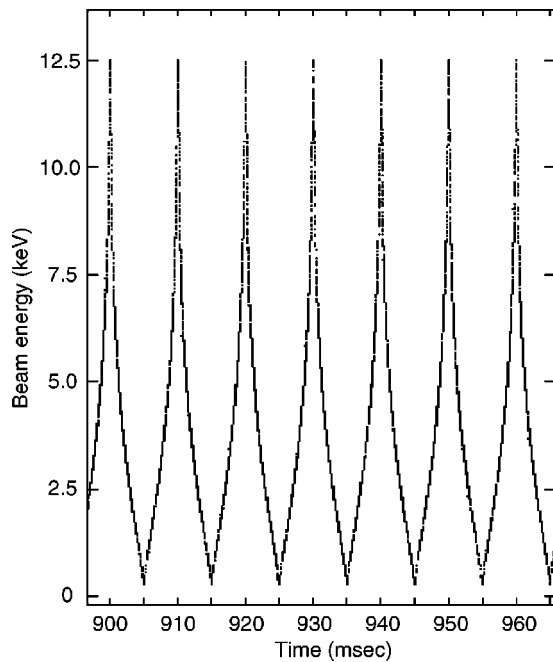
FIG. 4. Detector events plotted as a function of electron beam energy and time revealing the sweep pattern of the beam energy. The time dependence was chosen to reproduce the energy distribution in a Maxwellian distribution at a temperature of 2.5 keV. At the same time the electron beam current (not shown) is modulated so as to keep the electron density constant.

FIG. 5. Gold x-ray emission: (a) total emission produced by a 2.5 keV simulated Maxwellian; (b) contributions from selected dielectronic resonances.

being acquired. It should be noted that on-line sorts do not inhibit the work of the list processor.

If there are no events during a readout cycle, the block size will be zero, i.e., the block would contain no data. The off-line instrument gives an error message when it encounters an empty block and quits. Thus, subsequent blocks cannot be read with the offline instrument. To prevent this problem, the readout pulse is inhibited unless at least one event was digitized during the cycle. A Phillips 759 Gate and Delay Generator is used to accomplish this. The Phillips module is triggered by the readout pulse. But the module is set to ''latch'' so that a pulse can only pass through if the reset was triggered. The latter is accomplished by fanning out the gate pulse that triggers the ADCs to the reset.

In order to make the system useful for time resolved spectroscopy, the time at which an event occurs is recorded by the scaler. To do so, a pulse from the EBIT control unit resets the scaler and marks the start of the time measurement. The clock itself is generated by a Hewlett Packard 3314A arbitrary function generator whose signal is fed into the scaler. The scaler can process at a rate of up to 100 MHz, so submicrosecond accuracy, for example, for measurements of radiative lifetimes of metastable levels is possible.

III. OPERATION AND PERFORMANCE

We have used the new data acquisition system to record the $n=4,5$ to $n=3$ emission of highly ionized gold ions. This measurement was carried out using a newly implemented control system to generate a quasi-Maxwellian electron distribution function in EBIT. This system allows us to dial up a given electron temperature by properly program-
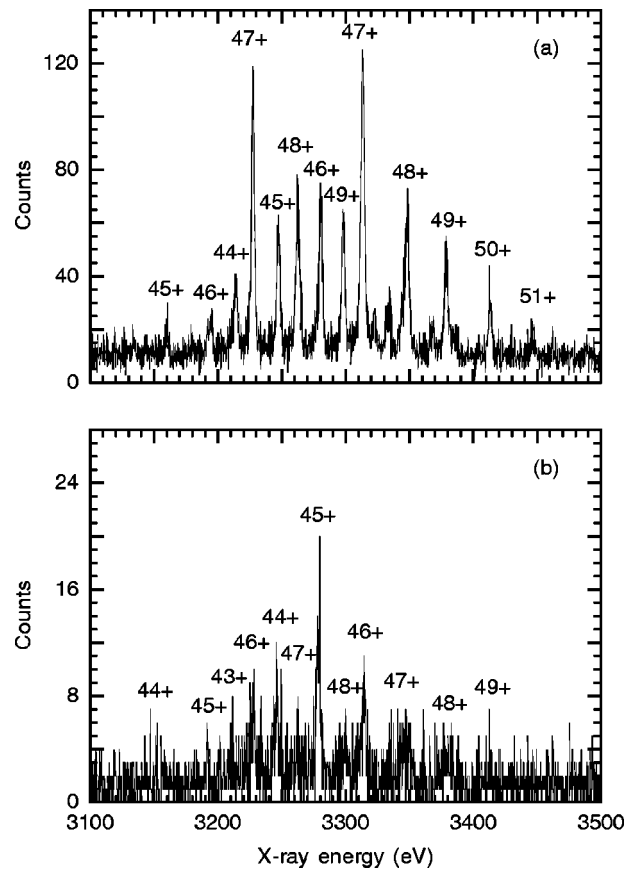
ming a set of arbitrary function generators that control the electron beam energy and the electron beam current.[3] These parameters are swept rapidly in time so that the electron distribution when integrated over half of one period closely resembles that of a Maxwellian distribution. For the present measurement, we selected an electron temperature of 2.5 keV.

The x-ray emission was recorded with two broadband crystal spectrometers[4] operating *in vacuo*. Employing four position-sensitive proportional counters and four Si (111) crystals the two instruments covered the wavelength band 2.5–4.5 Å.

The spectral response of one of the detectors as a function of electron beam energy is shown in Fig. 3. To reproduce the electron energy distribution of a 2.5 keV Maxwellian the energy sweeps from $E_{min}=300$ eV to $E_{max}=12\,500$ eV. A plot of the counts recorded with the detector as a function of time and beam energy is shown in Fig. 4. This figure reveals the sweep pattern as a function of time. The sweep period is 10 ms, which is sufficiently fast that the ionization balance does not change significantly within a period. Displaying the spectral response as a function of beam energy allows us to isolate contributions to the spectrum arising from very specific excitation processes such as dielectronic recombination, resonance excitation, and radiative cascades. Figure 5(a) shows the total spectrum observed at a quasitemperature of 2.5 keV. It represents the projection of the entire spectral emission observed in Fig. 3 onto the wave-
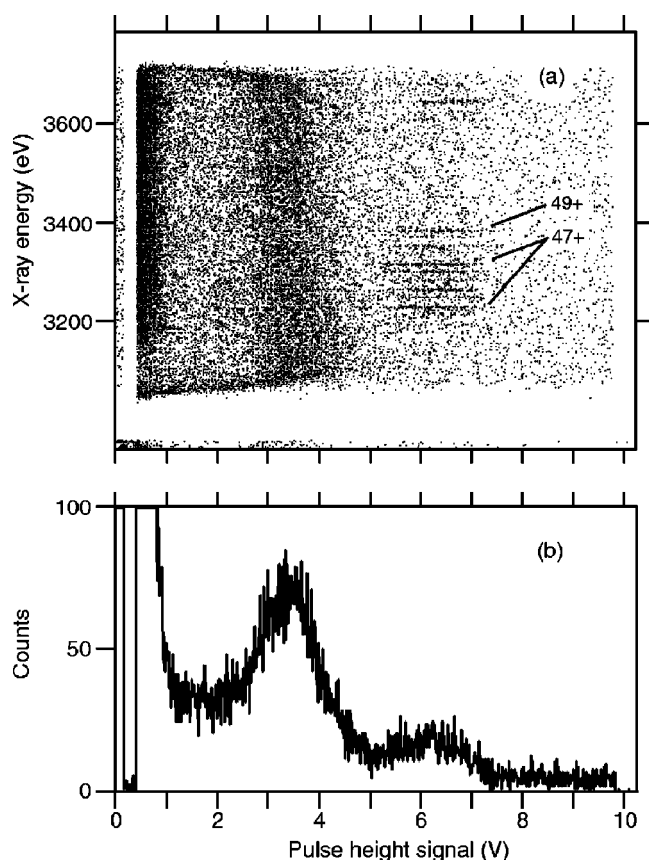
FIG. 6. Pulse height distribution in the position-sensitive proportional counter: (b) 1D plot; (a) 2D plot showing the range containing the actual spectral emission. Emission lines from Ge-like Au^{47+} and Zn-like Au^{49+} are labeled for reference. Counts seen near zero on both axes are unphysical and arise from operating the Phillips TDC (digitizing the proportional counter-position information) and the Phillips ADC (digitizing the proportional counter pulse height signal) in dither mode.
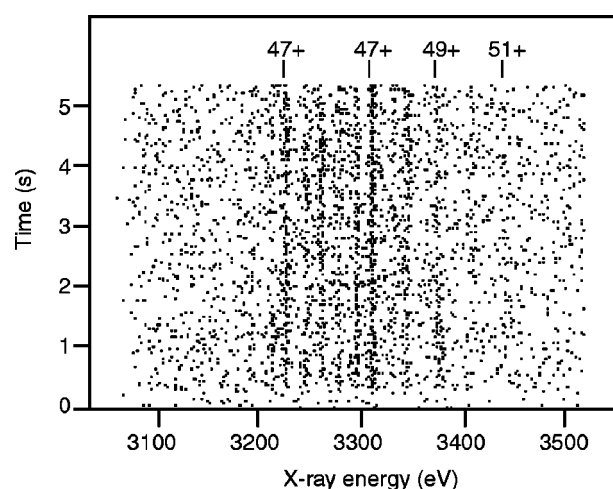

FIG. 7. Temporal evolution of the spectral emission. The trap is filled at $t = 0.3$ s and emptied at $t = 10$ s (not shown). Emission features are labeled by the charge state of the emitting ion.

reached is an important parameter for comparing the measured charge balance with calculations.[5]

IV. CONCLUSION

Through the large number of independent parameters that are digitized simultaneously, the new data acquisition system has provided us with opportunities to perform measurements with higher reliability (e.g., by knowing when the charge balance reaches steady state), better signal-to-noise ratios (e.g., by suppressing cosmic ray-induced background and by following drifts in the pulse-height distribution as a function of time), and less expensively (e.g., by reducing the number of hardware modules required to set gates). It has also opened up new classes of measurements, including multiple coincidence measurements,[6] precise radiative lifetime measurements,[7] and charge transfer measurements.[8] As a result of this versatility, we are installing the fourth such system at our trap experiment.

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length axis. Figure 5(b), for comparison, show the contributions of the lowest dielectronic resonance observed in Fig. 3. The comparison shows that the dielectronic resonance contributions are less than 10% of the total emission.

When displaying the spectral emission we have made use of the fact that we also digitize the pulse height distribution of the events recorded with the position-sensitive proportional counter. This distribution is shown in Fig. 6(b). From that figure it is not obvious where the gates need to be set to select only those events that actually represent gold x rays. Selection of the proper gates is made clear when plotting the spectral response versus the pulse height distribution. This is shown in Fig. 6(a). Selecting the proper gates greatly increases the signal to noise ratio of the measurement.

An additional benefit of archiving data in event-mode fashion is that we can display the temporal evolution of the spectral emission. This gives us information on how the ionization balance changes from the time when the trap is filled with new ions (starting with singly charged ions) to the time when we empty the trap. This evolution is shown in Fig. 7. The gold ions are still in an ionizing stage early in time. The data show that a steady-state ionization balance is reached after about 1 s. The time when ionization equilibrium is

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